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3 and 11–13 Cornmarket, Pontefract, West Yorkshire

Tree-ring Analysis of Oak Timbers

Alison Arnold and Robert Howard

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3 AND 11–13 CORNMARKET, PONTEFRACT, WEST YORKSHIRE

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SUMMARY

Analysis undertaken on samples from 3 and 11–13 Cornmarket resulted in the successful dating of 16 timbers. The front and rear range roofs of 3 Cornmarket are likely to be contemporary, with the timber utilised within them being felled in the ranges AD 1605–30 and AD 1606–30, respectively. The rear range roof also contains a timber, presumably reused or possibly stockpiled, felled in AD 1587. The crown post from the roof of 11–13 Cornmarket was felled in *c* AD 1590 with two other timbers, both with a *terminus post quem* for felling of AD 1556, likely to be coeval with this late sixteenth century felling date. The remaining dated timber from 11–13 Cornmarket has a *terminus post quem* for felling of AD 1480 and could thus represent either an earlier felling phase or could be a heavily trimmed inner-section of a much longer-lived tree.

CONTRIBUTORS

Alison Arnold and Robert Howard

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INTRODUCTION

The buildings 3 and 11–13 Cornmarket are part of a row of what was originally houses, now shops and offices, located on the south-west side of Cornmarket, in the market town of Pontefract (Figs 1–3). They are thought to date to the seventeenth century, or possibly earlier, but with numerous later alterations and additions.

3 Cornmarket

This building is of two-storeys plus lofts and consists of a front and rear range (Figs 3 & 4). It is constructed of brick with a slate roof and has four dormer windows. The roof over the front range consists of four principal rafter and tiebeam with collar trusses, between which are two sets of purlins and common rafters (Fig 5). There are also two surviving wall posts. The roof over the rear range has three principal rafter and tiebeam trusses, between which are common rafters and double staggered purlins (Fig 6). One wall post survives at first-floor level and three large jetty joists are visible at ground-floor level.

11–13 Cornmarket

This building is also of two storeys, formerly with a loft, and consists of a front range (11) and rear range (13), broadly in line with the front range (Figs 3 & 7). It is also constructed of brick with a steeply pitched slate covered roof. Most of the timbers of the roof are no longer visible but one truss can be seen to consist of principal rafters, crown post, posts, studs and rails; there is a single set of purlins (Fig 8) and the collar of a second truss is visible above the doorway (Fig 9).

SAMPLING

Dendrochronological analysis was requested by Zoe Kemp, Historic England Heritage at Risk Surveyor, to provide precise dating evidence for the primary construction of these rare surviving timber-framed buildings to inform their future protection and their overall significance in their historic setting.

Twenty-five timbers from the front and rear ranges at 3 Cornmarket were sampled by coring; additionally, a tenon from a cut-off collar was removed from a mortice in a principal rafter of truss 3, providing a further sample. Each sample was given the code PFR-A and numbered 01–26.

Six samples were taken from 11–13 Cornmarket; these were given the code PFR-B and numbered 01–06.

The location of all samples was noted at the time of sampling and has been marked on Figures 4 and 7. Further details relating to the samples can be found in Table 1. Trusses have been numbered from east to west (3 Cornmarket, front range) and north to south (3 Cornmarket, rear range and 11–13 Cornmarket).

ANALYSIS AND RESULTS

Six samples, four samples from 3 Cornmarket (two from the front range and two from the rear range) and two samples from 11–13 Cornmarket had too few rings for secure dating and so were discarded prior to measurement. The remaining 26 samples were prepared by sanding and polishing and their growth-ring widths measured; the data of these measurements are given at the end of the report. All samples were then compared with each other by the Litton/Zainodin grouping programme (see Appendix), resulting in 16 samples matching to form four groups.

Firstly, two samples, one from 3 Cornmarket and one from 11–13 Cornmarket, matched each other and were combined at the relevant offset positions to form PFRASQ01, a site sequence of 117 rings (Fig 10). This site sequence was compared against a series of relevant reference chronologies where it was found to match consistently and securely at a first-ring date of AD 1471 and a last-measured ring date of AD 1587. The evidence for this dating is given in Table 2.

Secondly, three samples from 11–13 Cornmarket matched and were combined at the relevant offset positions to form PFRASQ02, a site sequence of 186 rings (Fig 11). This site sequence was compared against a series of relevant reference chronologies and was found to match at a first-ring date of AD 1403 and a last-measured ring date of AD 1588. The evidence for this dating is given in Table 3.

Two samples, both from 3 Cornmarket, matched each other and were combined at the relevant offset positions to form PFRASQ03, a site sequence of 61 rings (Fig 12). This site sequence was compared against a series of relevant reference chronologies for oak where it was found to match consistently and securely at a first-ring date of AD 1528 and a last-measured ring date of AD 1588. The evidence for this dating is given in Table 4.

Finally, nine samples from 3 Cornmarket grouped to form PFRASQ04, a site sequence of 111 rings (Fig 13). This site sequence was compared against a series of relevant reference chronologies for oak where it was found to match consistently and securely at a first-ring date of AD 1495 and a last-measured ring date of AD 1605. The evidence for this dating is given in Table 5.

Attempts to match the remaining 10 ungrouped samples by comparing them individually against the reference chronologies were unsuccessful and these remain undated.

INTERPRETATION

Tree-ring analysis has resulted in the successful dating of 16 timbers from the two buildings (Fig 14). Felling date ranges have been calculated using the estimate that 95% of mature oak trees in this region have 15–40 sapwood rings.

3 Cornmarket

Front range

Seven of the samples taken from the front range have been successfully dated. Five of these have broadly contemporary heartwood/sapwood boundary ring dates, suggestive of a single felling. The average heartwood/sapwood boundary ring date is AD 1590, allowing an estimated felling date range to be calculated to within the range AD 1605–30. The other two samples do not have the heartwood/sapwood boundary ring but, with last-measured ring dates of AD 1582 (PFR-A06) and AD 1586 (PFR-A02), these have a *terminus post quem* for felling of AD 1597 and AD 1601, respectively. This, combined with the overall level of cross-matching suggests that the two timbers represented were also likely to have been felled in the AD 1605–30 range identified.

Rear range

Five of the samples taken from the rear range have been dated. One of these, PFR-A21, has complete sapwood and the last-measured ring date of AD 1587, the felling date of the timber represented. The other four samples have the heartwood/sapwood boundary ring which is broadly contemporary and suggestive of a single felling. The average heartwood/sapwood boundary ring date is AD 1590, giving an estimated felling for the timbers represented within the range of AD 1606–30. This allows for sample PFR-A19 having a last-measured ring date of AD 1605 with incomplete sapwood.

11–13 Cornmarket

Four of the samples from this building have been successfully dated. One of these, PFR-B01, was taken from a timber with complete sapwood but *c* 2mm of the sapwood rings were lost during sampling. It is estimated, based on the average ring width, that *c* 2 rings have been lost in those *c* 2mm. Thus adding two rings to the last-measured ring date of AD 1588 gives the timber represented a felling date of *c* AD 1590.

None of the other three samples have the heartwood/sapwood boundary ring and so estimated felling dates cannot be calculated for the timbers represented. However, with last-measured heartwood ring dates of AD 1465 (PFR-B04) and AD 1541 (PFR-B03 and PFR-B06) the timbers represented have a *terminus post quem* for felling of AD 1480 and AD 1556, respectively. The level of cross-matching between PFR-B03 and PFR-B04 suggests that they are likely to be coeval and the level of cross-matching between PFR-B03 and PFR-B01 is such that it suggests that both PFR-B03 and PFR-B04 are likely to have been felled in, or around, AD 1590. In addition, the level of cross-matching between PFR-B06 and PFR-A21 suggests that PFR-B06 was also felled in, or around, AD 1587. Thus all four dated timbers from this building appear likely to have been felled at a similar time towards the end of the sixteenth century.

DISCUSSION

Prior to the tree-ring dating being undertaken 3 Cornmarket was thought to date to the seventeenth century, a suggestion now supported by the dendrochronology. The roof of the front range contains timber dated to AD 1605–30 with the majority of the timber utilised within the rear range dating to AD 1606–30. The similarity of the felling date ranges calculated for both roofs suggest contemporary construction for the two ranges in the first decades of the seventeenth century. This interpretation is supported by a number of possible same-tree matches which were identified within the samples. These include PFR-A03 (from the front range) and PFR-A18 (from the rear range) which match each other at $t = 14.3$ and PFR-A03 (from the front range) and PFR-A17 (from the rear range) which match at $t = 10.7$. Other potential same-tree matches within samples from the same ranges are PRF-A02 and PFR-A06, both from the front range, matching each other at $t = 12.4$ and PFR-A17 and PFR-A18, both from the rear range, matching at a level of $t = 10.6$.

The cut off tenon from a collar (sample PFR-A21) in the rear range of 3 Cornmarket has been dated somewhat earlier with a felling date of AD 1587. It is thought likely that this timber must have been either reused or possibly stockpiled. Indeed, with timber dated to *c* AD 1590 being identified within 11–13 Cornmarket it is tempting to think that this timber might have been left over from the construction programme associated with 11–13 which is after all part of this long row of houses that are assumed to be broadly coeval. The possibility that these two timbers may belong to the same programme of felling, potentially spanning a small number of years, is perhaps supported by the fact that PFR-A21 matches against PFR-B06 at a much higher value ($t = 7.0$) than it does against any of the samples within 3 Cornmarket.

Tree-ring dating has also identified at least one late-sixteenth century timber within the roof of 11–13 Cornmarket with the dating of a crown post to *c* AD 1590. The other three dated samples from this roof with *terminus post quem* felling dates of AD 1480 and AD 1556 (two timbers), combined with the levels of cross-matching, appear likely to have also been felled within a few years of AD 1590. For sample PFR-B04 (*terminus post quem* felling of AD 1480) to have been felled at the end of the sixteenth century it would have to be the inner section of a much longer lived tree. However, given this sample has only 42 growth rings and PFR-B01 and PFR-B03 each have more than 100 growth rings it would not be surprising if this was the case. This does emphasise the caution required when basing an interpretation of likely construction date of a building on only a few dated samples. However, the results indicate building activity taking place towards the end of the sixteenth century, suggesting the possibility that 11–13 Cornmarket has origins slightly earlier than the previously presumed seventeenth century date.

Despite the dated samples being reasonably coeval they have formed four disparate groups which suggests more than one woodland source was utilised for the timber in their construction. Where these woodlands might be is unknown but the reference chronologies against which these four site sequences match most highly tend to be located in West Yorkshire and the Midlands (Tables 2–5) which would suggest relatively local sources for the timber.

BIBLIOGRAPHY

Arnold, A J, Howard, R E, Laxton, R R, and Litton, C D, 2002 *The Urban Development of Newark-on-Trent: A Dendrochronological Approach*, Centre for Archaeol Rep, 95/2002

Arnold, A J, Howard, R E, Litton, C D, and Dawson, G 2005 *The Tree-ring Dating of a Number of Bellframes in Leicestershire*, Centre for Archaeol Rep, 5/2005

Arnold, A J and Howard, R E, 2005 *Tree-ring analysis of timbers from the Main Guard, Pontefract Castle*, Centre for Archaeol Rep, 48/2005

Arnold, A J, Howard, R E, and Litton, C D, 2008a Nottingham Tree-ring Dating Laboratory: additional dendrochronology dates, *Vernacular Architect*, 39, 107–11

Arnold, A J, Howard, R E, and Tyers, C, 2008b *Bishopsthorpe Palace, Bishopsthorpe, York, tree-ring analysis of timbers*, English Heritage Res Dep Rep Ser, 57/2008

Arnold, A J, and Howard, R E, 2011 unpubl Tree-ring analysis of timbers from Aslackby Manor, Aslackby, Lincolnshire unpubl computer file *ASBASQ01/ 02/ 03,* NTRDL

Arnold, A and Howard, R, 2013 unpubl Tree-ring analysis of timbers from Preston Manor House, Cross Lane, Preston, Rutland unpubl computer file *PSTASQ01,* NTRDL

Arnold, A J and Howard, R E, 2013a *Tree-ring analysis of timbers from Bramall Hall, Bramall, Stockport, Greater Manchester*, NTRDL Rep

Arnold, A J and Howard, R E, 2013b *Howley Hall, Morley, West Yorkshire; Tree-ring analysis of timbers*, NTRDL Rep

Arnold, A, Howard, R, and Tyers, C, forthcoming *Ledston Hall, Hall Lane, Ledston, Leeds, West Yorkshire , tree-ring analysis of oak timbers*, Historic England Res Rep Ser,

Boswijk, G, 1997 *Tree-ring analysis of oak timbers from Thorpe Barn, Finthorpe, near Huddersfield*, ARCUS Rep, 339

Howard, R E, 1990 unpubl Tree-ring analysis of timbers from Oliver Cromwell's House, Ely, Cambridgeshire, unpubl computer file *ELYASQ01*, NTRDL

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1992 Nottingham University Tree-Ring Dating Laboratory: results, *Vernacular Architect*, 23, 51–6

Howard, R E, Laxton, R R, and Litton, C D, 1999 *Tree-ring analysis of timbers from Bretby Hall, Bretby, Derbyshire*, Anc Mon Lab Rep, 43/99

Howard, R E, Laxton, R R, and Litton, C D, 2000a *Tree-ring analysis of timbers from Clumpcliff Farm, Methley Lane, Rothwell, nr Oulton, W Yorks*, Anc Mon Lab Rep, 13/2000

Howard, R E, Laxton, R R, and Litton, C D, 2000b *Tree-ring analysis of timbers from the buildings and living trees at Stoneleigh Abbey, Stoneleigh, Warwickshire*, Anc Mon Lab Rep, 80/2000

Howard, R E, Laxton, R R, and Litton, C D, 2003 *Tree-ring analysis of timbers from Combermere Abbey, Whitchurch, Cheshire*, Anc Mon Lab Rep, 83/2003

Howard, R E, 2004 unpubl Sandiacre Tithe Barn, Derbyshire, unpublished computer file *STBASQ01 / 02*, NTRDL

Howard, R E, 2005 unpubl Tree-ring analysis of timbers from Harvington Hall Barn, Harvington, Worcestershire, unpubl computer file *HVTCSQ02*, NTRDL

Hurford, M, Arnold, A J, Howard, R E, and Tyers, C, 2008 *Tree-ring analysis of timbers from Flore's House, High Street, Oakham, Rutland,* English Heritage Res Dep Res Rep, 94/2008

Miles, D, Haddon-Reece, D, Moran, M, and Mercer, E, 1993 Tree-ring dates for buildings: List 54, *Vernacular Architect*, 24, 54-60

Miles, D H, and Worthington, M J, 1998 Tree-ring dates for buildings: List 90, *Vernacular Architect*, 29, 111-7

Tyers, I, 1997 *Tree-ring analysis of timbers from Sinai Park, Staffordshire*, Anc Mon Lab Rep, 80/97

Tyers, I, 1999 *Dendrochronological analysis of timbers from Black Ladies, near Brewood, Staffordshire*, ARCUS Rep, 484

TABLES

Table 1: Details of samples from Numbers 3 and 11–13 Cornmarket, Pontefract, West Yorkshire

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
3 Cornmarket						
Front range						
PFR-A01	South principal rafter, truss 1	NM	--	----	----	----
PFR-A02	North principal rafter, truss 2	80	--	1507	----	1586
PFR-A03	South principal rafter, truss 3	81	16	1523	1587	1603
PFR-A04	Tiebeam, truss 2	51	h/s	1536	1586	1586
PFR-A05	South post, truss 2	52	--	----	----	----
PFR-A06	South principal rafter, truss 3	88	--	1495	----	1582
PFR-A07	Tiebeam, truss 3	61	h/s	1528	1588	1588
PFR-A08	South post, truss 3	NM	--	----	----	----
PFR-A09	South principal rafter, truss 4	80	07	1519	1591	1598
PFR-A10	Tiebeam, truss 4	78	07	1526	1596	1603
PFR-A11	North lower purlin, truss 1–2	57	15C	----	----	----
PFR-A12	South lower purlin, truss 1–2	56	10	----	----	----
Rear range						
PFR-A13	Tiebeam, truss 1	48	h/s	----	----	----
PFR-A14	East post, truss 1	49	--	----	----	----
PFR-A15	East principal rafter, truss 1	56	08	----	----	----
PFR-A16	Upper collar, truss 1	59	--	----	----	----
PFR-A17	East principal rafter, truss 2	98	04	1497	1590	1594
PFR-A18	West principal rafter, truss 2	73	04	1523	1591	1595
PFR-A19	East principal rafter, truss 3	53	15	1553	1590	1605
PFR-A20	West principal rafter, truss 3	64	07	1534	1590	1597
PFR-A21	Collar, truss 3	92	30C	1496	1557	1587
PFR-A22	East lower purlin, truss 1-north gable	98	33	----	----	----
PFR-A23	West lower purlin, truss 1–2	46	h/s	----	----	----

Table 1: (continued)

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
PFR-A24	East upper purlin, truss 1–2	65	34C	----	----	----
PFR-A25	East upper purlin, truss 2–3	NM	--	----	----	----
PFR-A26	West upper purlin, truss 2–3	NM	--	----	----	----
11-13 Cornmarket						
PFR-B01	Crown post, truss 3	106	26c(+*c*2lost)	1483	1562	1588
PFR-B02	North brace, truss 3 to collar purlin	NM	--	----	----	----
PFR-B03	Upper west cross rail, truss 3	139	--	1403	----	1541
PFR-B04	Lower west cross rail, truss 3	42	--	1424	----	1465
PFR-B05	East purlin, truss 2–3	NM	--	----	----	----
PFR-B06	Collar, truss 2	71	--	1471	----	1541

NM = not measured
h/s = heartwood/sapwood boundary is the last-measured ring
C = complete sapwood retained on sample, last measured ring is the felling date
c(+*c*2lost) = complete sapwood on timber, all or part lost in sampling with estimated number of lost rings in brackets.

Table 2: Results of the cross-matching of site sequence PFRASQ01 and relevant reference chronologies when the first-ring date is AD 1471 and the last-measured ring date is AD 1587

Reference chronology	*t*-value	Span of chronology	Reference
Church of St Andrew, Welham, Leicestershire	7.8	AD 1443–1633	Arnold *et al* 2005
Clumpcliff, Wakefield, West Yorkshire	7.6	AD 1452–1613	Howard *et al* 2000a
Flore's House, Oakham, Rutland	7.3	AD 1408–1591	Hurford *et al* 2008
Manor House, Preston, Rutland	7.3	AD 1471–1631	Arnold and Howard 2013 unpubl
Aslackby Manor, Lincolnshire	7.1	AD 1462–1539	Arnold and Howard 2011 unpubl
Nun Appleton, Tadcaster, West Yorkshire	6.8	AD 1478–1657	Arnold *et al* 2008a
Sandiacre Tithe Barn, Derbyshire	6.6	AD 1427–1611	Howard 2004 unpubl

Table 3: Results of the cross-matching of site sequence PFRASQ02 and relevant reference chronologies when the first-ring date is AD 1403 and the last-measured ring date is AD 1588

Reference chronology	*t*-value	Span of chronology	Reference
Bishopsthorpe Palace, York, Yorkshire	6.6	AD 1360–1527	Arnold *et al* 2008b
Bramall Hall, Bramall, Stockport, Greater Manchester	6.3	AD 1359–1590	Arnold and Howard 2013a
Stoneleigh Abbey, Stoneleigh, Warwickshire	6.2	AD 1398–1658	Howard *et al* 2000b
Sinai Park, Burton on Trent, Staffordshire	6.0	AD 1227–1750	Tyers 1997
Brookgate Farm, Plealy, Shropshire	6.0	AD 1362–1611	Miles *et al* 1993
Combermere, Cheshire	5.9	AD 1363–1564	Howard *et al* 2003
Black Ladies, Brewood, Staffordshire	5.8	AD 1372–1671	Tyers 1999

Table 4: Results of the cross-matching of site sequence PFRASQ03 and relevant reference chronologies when the first-ring date is AD 1528 and the last-measured ring date is AD 1588

Reference chronology	*t*-value	Span of chronology	Reference
Bretby Hall, Derbyshire	6.5	AD 1494 –1719	Howard *et al* 1999
Pontefract Castle, West Yorkshire	6.1	AD 1507–1656	Arnold and Howard 2005
Thorpe Barn, Finthorpe, West Yorkshire	6.0	AD 1391–1594	Boswijk 1997
Manor Farm (south-west wing), Stanton St John, Oxfordshire	5.5	AD 1480–1646	Miles and Worthington1998
Harvington Hall Barn, Harvington, Worcestershire	5.1	AD 1390–1584	Howard 2005 unpubl
Manor Farm (stables), Stanton St John, Oxfordshire	4.9	AD 1533–1637	Miles and Worthington 1998
Oliver Cromwell's House, Ely, Cambridgeshire	4.8	AD 1480–1611	Howard 1990 unpubl

Table 5: Results of the cross-matching of site sequence PFRAQ04 and relevant reference chronologies when the first-ring date is AD 1495 and the last-measured ring date is AD 1605

Reference chronology	*t*-value	Span of chronology	Reference
Ledston Hall, Ledston, West Yorkshire	8.0	AD 1424–1668	Arnold *et al* forthcoming
Black Ladies, Brewood, Staffordshire	8.0	AD 1372–1671	Tyers 1999
Howley Hall, West Yorkshire	7.6	AD 1415–1632	Arnold and Howard 2013b
Speke Hall, Merseyside	7.6	AD 1387–1598	Howard *et al* 1992
17/21 Boar Lane, Newark, Nottinghamshire	7.6	AD 1507–1657	Arnold *et al* 2002
Church of St Andrew (bellframe), Welham, Leicestershire	7.6	AD 1443–1633	Arnold *et al* 2005
Manor House, Preston, Rutland	7.6	AD 1471–1631	Arnold and Howard 2013 unpubl

FIGURES

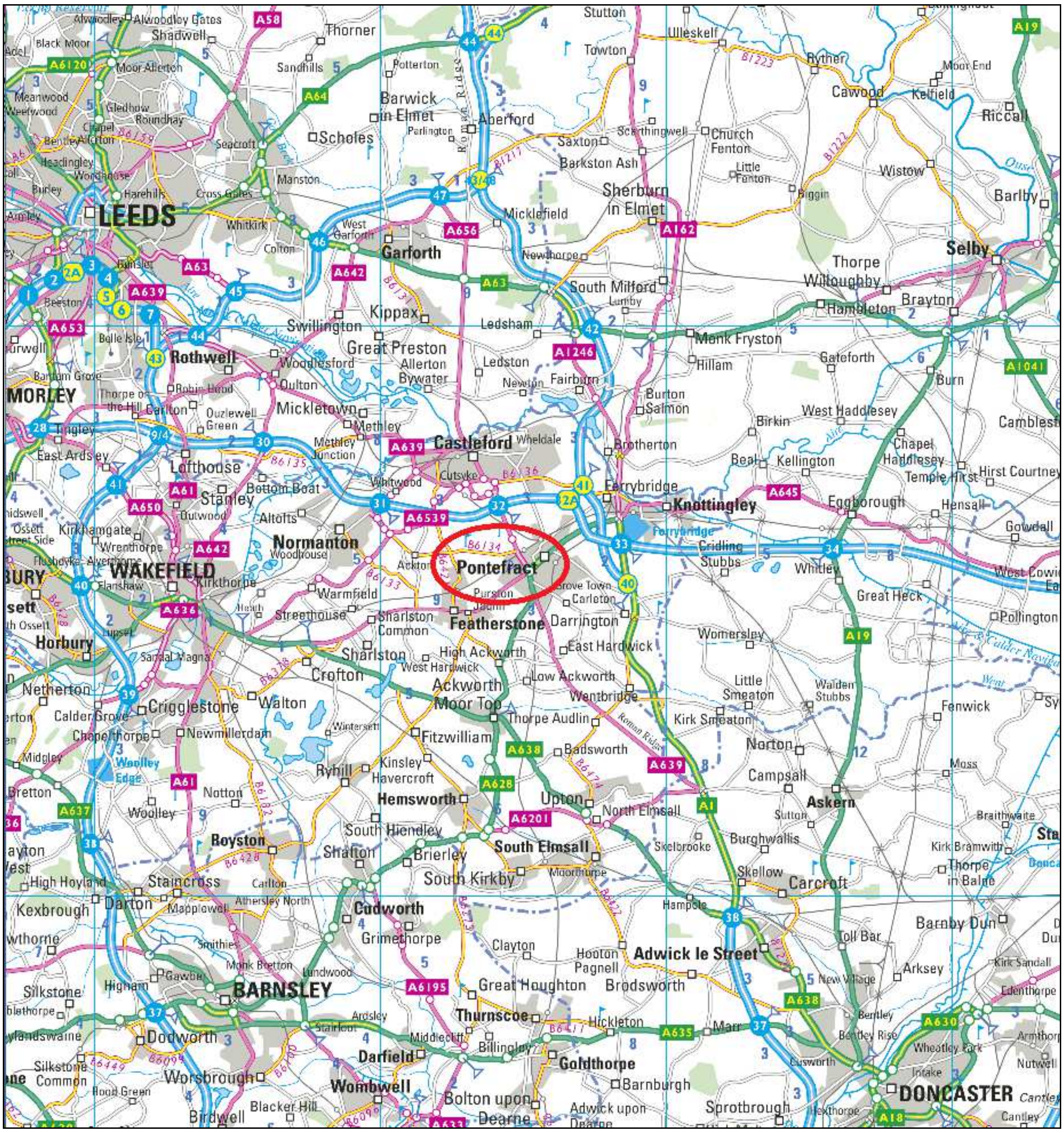

Figure 1: Map to show the general location of Pontefract, circled. © Crown Copyright and database right 2015. All rights reserved. Ordnance Survey Licence number 100024900

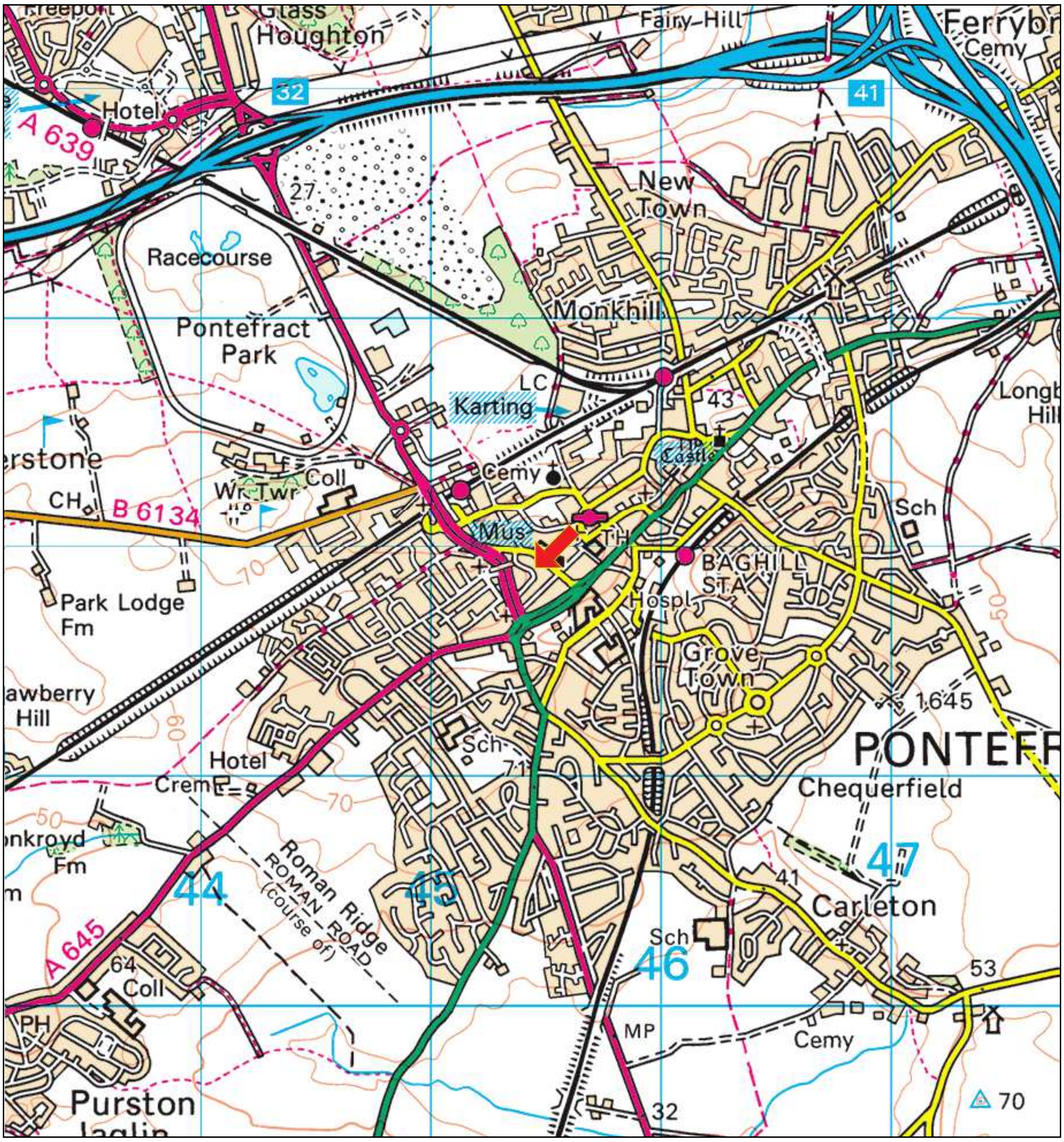

Figure 2: Map to show the general location of Cornmarket, arrowed. © Crown Copyright and database right 2015. All rights reserved. Ordnance Survey Licence number 100024900

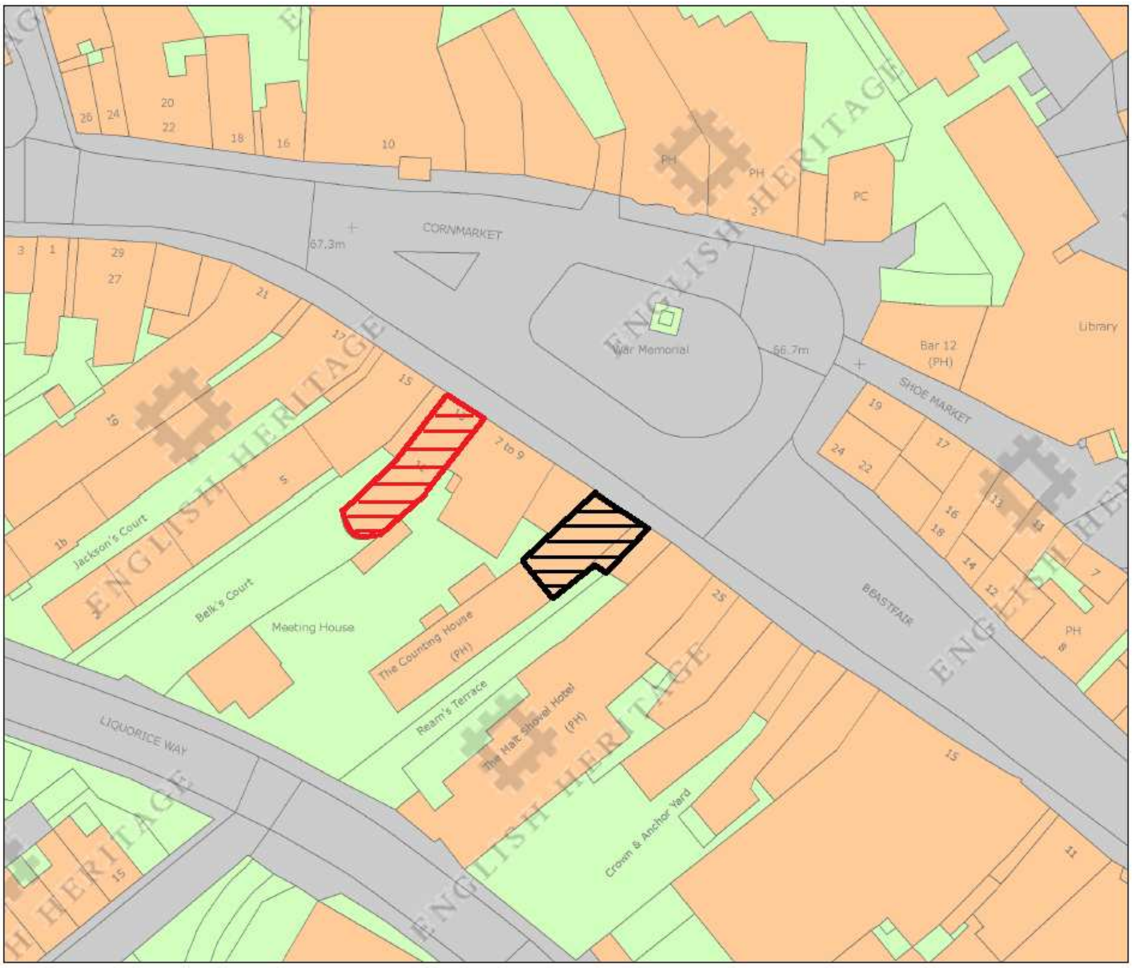

Figure 3: Map to show the location of Numbers 3 (in black) and Numbers 11–13 (in red), Cornmarket, Pontefract. © Crown Copyright and database right 2015. All rights reserved. Ordnance Survey Licence number 100024900

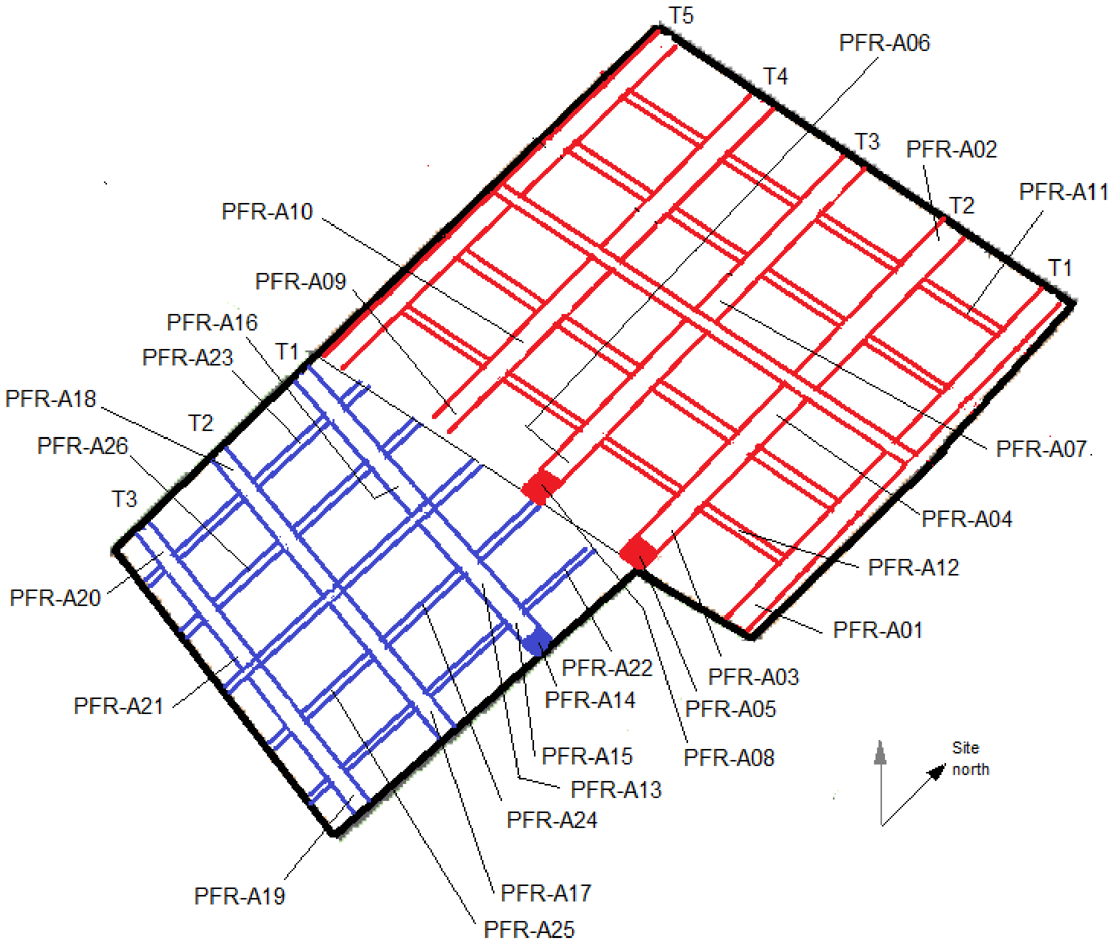

Figure 4: 3 Cornmarket, sketch plan of the front (in red) and rear (in blue) ranges, showing the location of samples PFR-A01–2

Figure 5: 3 Cornmarket, front range roof, truss 3 in foreground (Alison Arnold)

Figure 6: 3 Cornmarket, rear range roof, truss 1 in foreground (Robert Howard)

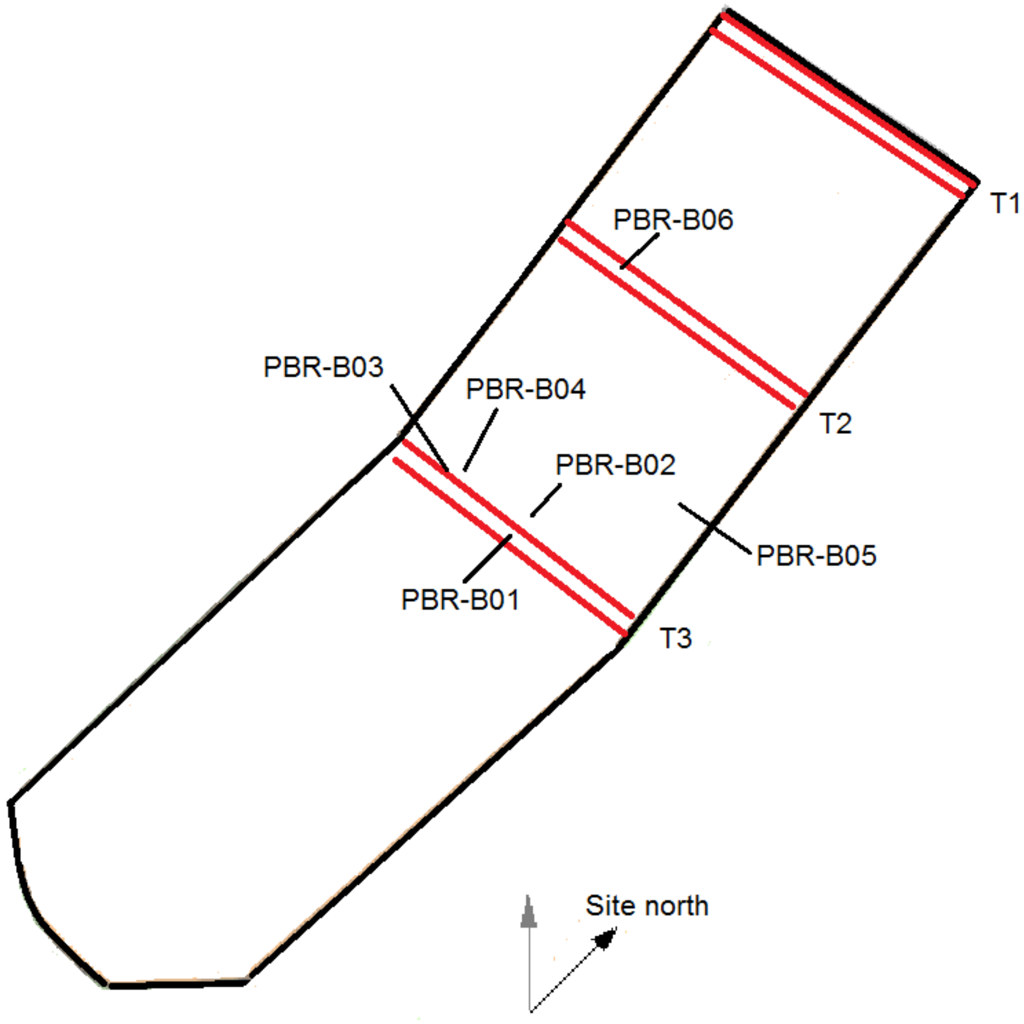

Figure 7: 11-13 Cornmarket, sketch plan, showing the approximate position of trusses and the location of samples PBR-B01–06

Figure 8: 11–13 Cornmarket, truss 3, photograph taken from the north (Alison Arnold)

Figure 9: 11–13 Cornmarket, collar of truss 2, photograph taken from the north (Alison Arnold)

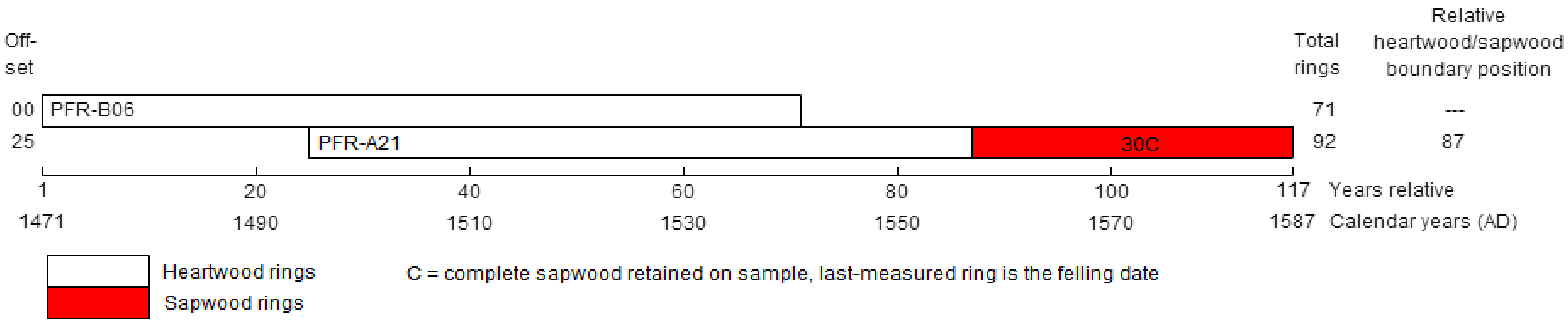

Figure 10: Bar diagram to show the relative position of samples in site sequence PFRASQ01

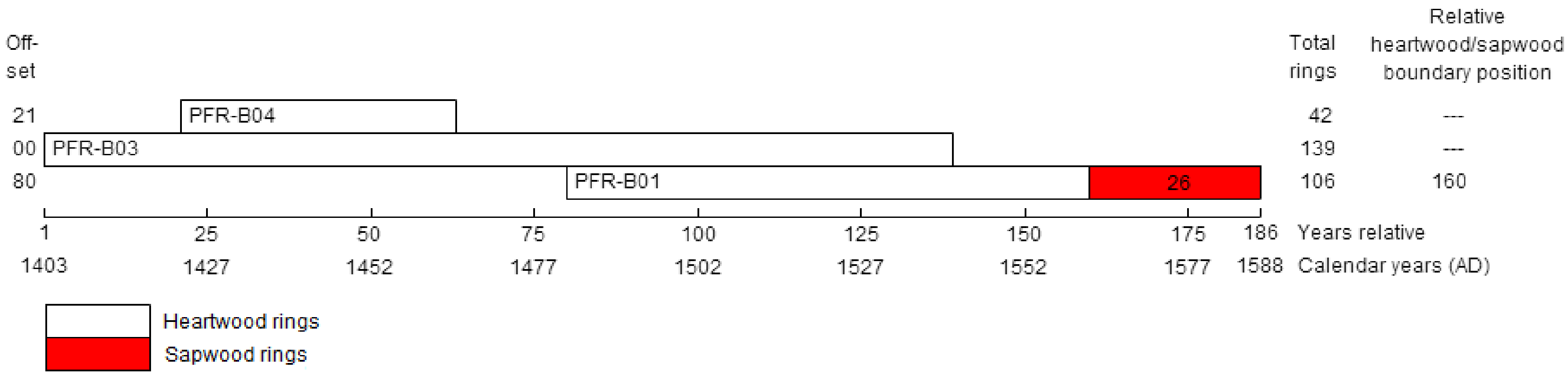

Figure 11: Bar diagram to show the relative position of samples in site sequence PFRASQ02

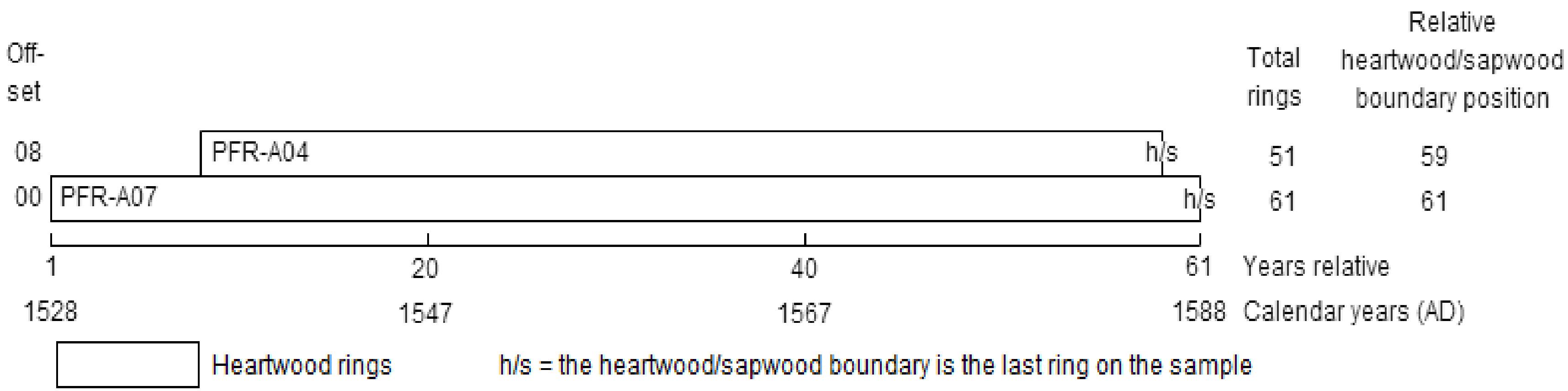

Figure 12: Bar diagram to show the relative position of samples in site sequence PFRASQ03

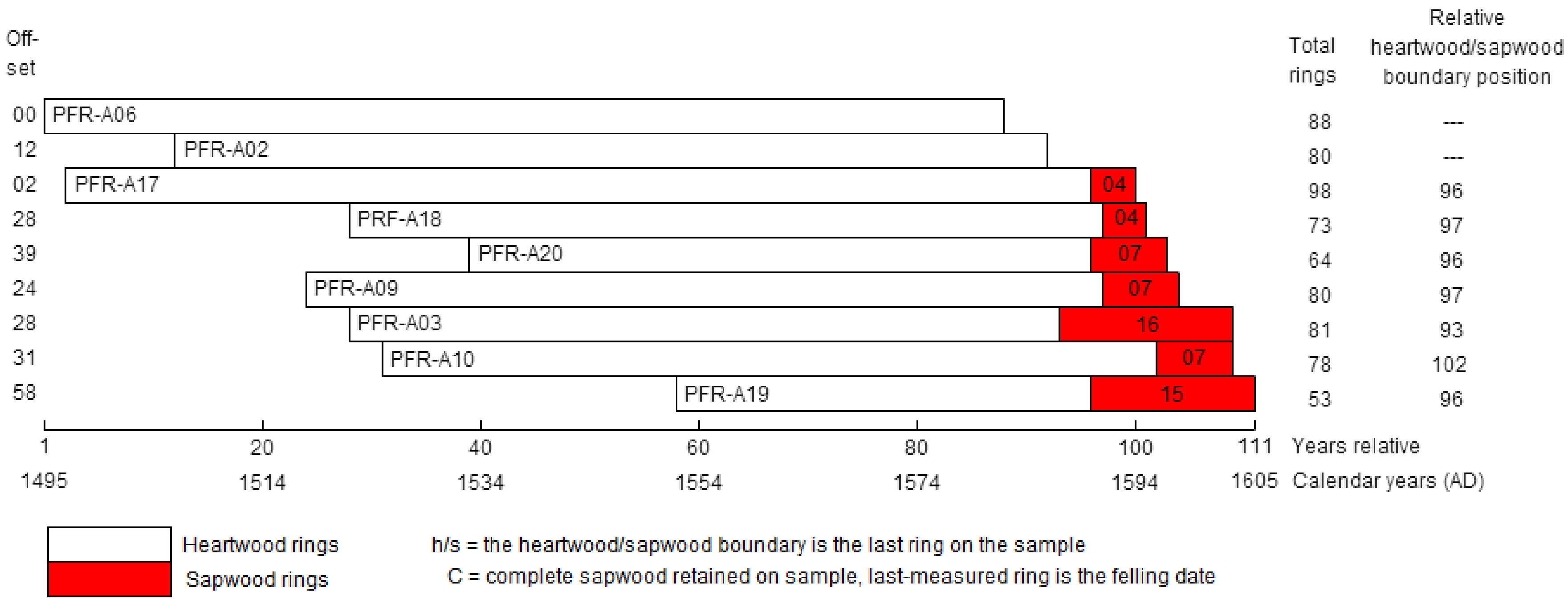

Figure 13: Bar diagram to show the relative positions of samples in site sequence PFRASQ04

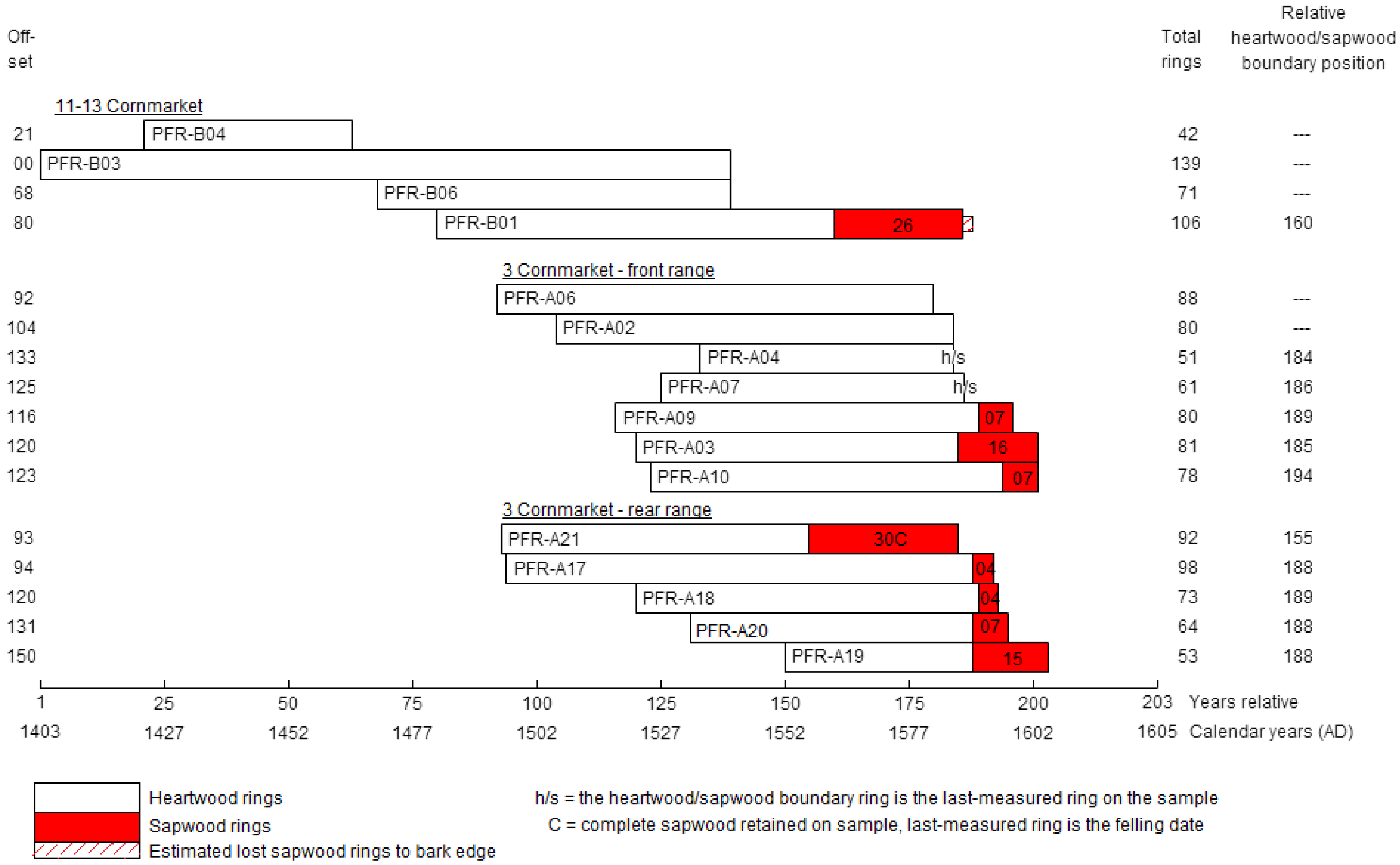

Figure 14: Bar diagram of dated samples, sorted by building and area

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

PFR-A02A 80
447 401 573 479 401 387 428 427 326 330 320 382 367 246 364 396 339 334 277 392
356 489 309 426 390 335 285 287 401 280 271 225 209 278 230 223 277 245 205 205
168 318 349 307 269 190 178 243 330 192 134 143 306 363 343 208 222 255 175 126
146 124 178 224 180 152 208 227 249 357 217 173 270 311 208 220 179 142 258 377
PFR-A02B 80
424 418 571 472 394 362 431 416 356 343 320 370 362 245 367 385 320 327 276 395
356 488 315 415 393 327 291 286 392 277 277 232 217 264 221 225 277 243 205 210
162 325 345 313 271 194 173 252 328 184 136 107 310 313 359 196 231 255 172 116
153 130 171 218 180 152 188 244 248 353 208 173 252 316 207 223 173 155 249 371
PFR-A03A 81
385 394 233 400 333 482 273 366 375 337 316 335 518 526 337 304 345 277 250 172
249 224 189 188 116 226 279 205 227 167 138 167 230 152 94 86 155 181 254 158
169 227 173 113 109 167 199 199 131 158 177 123 139 135 125 99 153 180 150 170
136 122 191 215 158 133 124 136 78 80 132 184 150 137 135 151 141 131 107 105
76
PFR-A03B 80
357 354 241 373 344 413 277 379 387 325 370 284 562 517 340 311 343 284 248 170
254 222 178 198 119 221 282 206 225 157 130 162 223 162 93 98 145 170 255 150
171 232 171 101 127 174 202 193 134 150 173 134 131 136 126 101 140 173 163 166
147 115 197 229 157 118 182 129 65 78 139 172 147 140 145 142 148 127 110 106
PFR-A04A 51
393 302 327 265 364 540 766 1003 1065 795 373 375 345 283 250 234 160 187 219 274
238 104 115 201 213 163 249 272 204 236 170 205 212 233 337 183 198 179 199 254
186 267 228 278 254 267 226 303 291 352 278
PFR-A04B 51
387 315 350 263 359 539 708 942 1011 787 365 344 371 275 244 233 150 178 205 276
236 101 115 204 212 190 253 267 205 243 157 209 207 241 342 184 191 182 197 250
184 271 235 275 251 248 221 317 300 348 322
PFR-A05A 52
403 799 971 894 215 189 164 309 349 530 544 524 534 481 446 485 426 611 634 403
429 786 642 593 533 129 62 60 31 40 73 61 127 196 150 271 240 375 253 156
276 265 390 322 326 335 308 246 291 272 156 207
PFR-A05B 52
371 796 949 927 197 168 168 290 354 425 533 518 534 481 435 475 432 623 633 401
424 770 634 594 532 124 66 57 35 38 70 61 122 200 147 277 240 370 256 145
277 267 384 337 344 321 313 257 289 274 159 182
PFR-A06A 88
437 521 695 607 654 719 624 557 369 458 455 352 367 317 718 601 572 485 410 338
337 445 511 535 607 326 483 491 359 314 290 307 353 360 200 239 218 288 256 239
280 264 291 362 304 329 281 234 266 237 177 182 141 255 328 346 317 246 214 314
400 217 156 219 283 345 296 148 198 243 131 114 170 173 229 374 271 216 246 207
208 273 244 197 270 359 216 225
PFR-A06B 88
425 527 693 600 663 718 616 553 363 459 457 350 371 330 706 583 576 479 428 377
344 434 513 537 610 321 464 497 361 324 286 310 348 362 200 241 236 284 250 237
271 261 301 363 312 330 275 234 267 224 183 189 136 267 318 349 333 239 215 306
412 220 158 212 282 348 310 148 207 239 133 116 167 169 229 381 265 215 249 210

202 273 238 186 280 363 228 227
PFR-A07A 61
335 348 270 347 384 359 328 549 388 464 531 346 138 152 216 184 202 276 193 236
294 383 298 349 256 283 320 257 284 125 120 304 240 238 240 289 351 476 397 457
492 522 658 442 441 439 454 363 275 268 302 282 316 276 258 284 389 415 373 292
192
PFR-A07B 61
343 357 272 348 394 359 338 553 403 471 540 347 135 149 213 215 198 276 182 237
293 387 298 360 254 283 323 259 277 119 124 308 249 223 255 270 372 501 402 459
495 519 654 457 436 432 455 364 281 261 297 290 320 275 249 290 362 393 383 303
202
PFR-A09A 80
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248 254 175 146 173 149 192 144 102 188 179 201 183 133 117 211 345 229 144 142
234 294 288 181 153 173 117 132 122 142 205 291 296 220 209 129 111 105 104 100
122 137 137 114 153 161 239 380 243 258 275 185 158 136 215 402 316 215 210 250
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239 235 184 131 171 132 183 156 105 183 176 194 192 138 125 213 341 244 155 147
230 287 298 180 154 169 110 133 129 132 196 284 310 209 210 125 108 110 104 96
122 137 133 119 147 157 236 395 242 245 286 183 137 147 177 409 314 221 248 186
PFR-A10A 78
292 400 488 417 311 300 347 333 333 298 259 200 199 226 321 327 220 307 355 306
243 238 282 291 274 299 172 185 224 227 215 161 135 167 250 301 366 343 248 236
235 213 302 246 371 345 249 275 385 395 244 337 468 466 586 471 345 333 340 316
426 320 260 352 269 204 204 242 366 326 282 342 420 329 279 336 315 369
PFR-A10B 78
319 407 485 423 313 307 347 342 323 295 270 207 183 224 326 329 224 300 356 304
250 235 277 269 273 303 170 187 218 248 223 157 131 164 254 289 387 361 253 238
243 211 295 248 367 351 255 277 400 369 249 389 470 476 587 485 350 335 343 324
422 309 253 339 273 211 198 231 363 326 245 296 438 332 259 355 322 358
PFR-A11A 57
186 259 188 229 127 118 300 374 435 355 325 335 228 234 234 273 212 266 245 222
240 245 157 73 87 86 166 188 415 458 559 482 423 307 228 219 209 124 151 192
245 328 246 253 234 238 214 199 179 165 351 287 216 212 208 249 91
PFR-A11B 57
185 259 193 221 125 118 300 375 447 360 325 340 226 227 247 243 219 272 228 239
251 247 162 76 79 92 166 184 409 457 562 483 416 314 235 212 214 134 152 189
242 332 247 266 229 246 212 202 183 178 329 280 211 222 240 211 83
PFR-A12A 56
400 284 215 163 202 141 151 139 202 141 127 109 235 296 187 244 200 176 174 198
159 166 199 177 171 211 334 233 202 158 122 129 157 201 190 196 209 222 207 215
163 113 99 70 88 165 144 247 217 220 155 167 138 98 122 92
PFR-A12B 56
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170 161 191 187 161 197 338 230 206 155 122 120 165 194 189 198 202 238 211 220
159 109 88 79 93 149 158 245 209 218 137 178 125 91 128 90
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202 183 173 193 230 297 261 225 199 178 174 165 153 139 171 179 199 239 234 202
207 219 255 293 291 196 192 118
PFR-A13B 48
245 283 261 125 167 241 289 245 247 184 171 156 269 197 176 158 178 242 237 269

203 183 164 187 234 300 252 229 198 181 172 166 144 148 171 179 202 234 243 207
205 215 238 305 286 193 194 122
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508 646 595 485 731 674 677 610 467 978 554 697 507 431 692 582 389 204 173 286
500 415 299 201 311 352 407 247 189 298 365 561 441 621 450 394 239 204 241 329
309 523 476 358 269 415 318 251 174
PFR-A14B 49
498 641 605 482 772 659 689 621 467 969 559 764 404 455 704 615 392 204 178 288
529 422 310 178 330 350 395 250 194 297 369 566 439 629 450 394 241 207 255 315
313 530 474 359 272 416 318 250 184
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497 510 432 261 339 311 280 272 221 255 189 148 176 199 181 168 245 314 287 382
493 377 303 227 310 169 166 239 336 170 188 128 129 173 109 100 97 121 129 150
140 116 127 129 124 125 107 134 136 140 142 153 151 141 171 157
PFR-A15B 56
493 485 413 275 337 303 281 238 219 252 212 161 166 223 185 166 248 310 289 408
521 346 310 237 257 165 169 222 321 189 186 124 140 169 109 101 100 134 135 154
157 109 131 130 107 126 111 140 134 129 147 152 147 145 171 155
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155 153 171 168 231 90 256 243 270 166 115 93 154 118 90 142 111 160 197 305
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PFR-A16B 59
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PFR-A17A 98
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181 141 147 176 162 112 143 163 196 134 84 95 151 148 178 240 201 199 192 271
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194 123 168 175 175 166 169 146 278 391 211 147 121 112 97 78 162 191
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196 182 385 520 287 192 245 207 126 137 220 223 156
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204 165 381 517 299 198 243 202 125 146 204 237 157
PFR-A19A 53
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202 154 148 127 117 133 173 176 138 170 158 134 196 226 171 184 228 147 117 116
220 251 239 221 200 253 209 241 242 211 280 225 194
PFR-A19B 53

186 230 320 211 128 131 162 257 271 200 177 239 209 160 182 175 203 235 203 204
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230 257 221 208 204 261 208 228 234 214 265 226 188
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241 209 184 236
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287 157
PFR-A21B 80
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207 178 194 291 262 198 167 194 171 149 159 232 184 196 179 190 157 114 139 160
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PFR-A22A 62
542 334 238 288 268 222 93 48 46 62 65 185 191 162 259 490 364 582 191 315
242 286 314 177 279 152 92 145 119 111 99 98 126 158 176 137 232 244 97 98
88 86 122 139 149 117 111 243 262 195 135 159 524 472 119 68 54 89 84 104
129 184
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214 76 226 219 145 198 196 137 114 103 187 198 159 122 157 498 444 122 75 62
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106 117 87 70 90 96 92 94 131 121 163 69 55 39 45 56 70 84 111 90
89
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155 90 96 118 88 54 54 65 94 107 133 139 141 105 91 131 123 107 106 84
67 71 73 94 126 87
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156 96 97 120 86 63 58 56 97 100 135 139 137 102 96 131 118 114 107 77
66 77 73 104 116 102
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104 63 95 112 128 164 169 199 247 232 169 98 93 96 102 111 123 156 162 170
178 238 273 172 140 113 79 77 88 104 114 110 95 77 68 61 69 59 65 92
89 80 101 109 122
PFR-A24B 65
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172 246 293 167 146 115 75 80 88 104 100 111 93 84 71 56 63 62 67 89
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135 155 108 123 134 118 104 108 129 116 101 110 97 135 144 152 131 123 182 100
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148 158 107 128 138 112 104 111 131 121 103 110 105 137 149 149 141 123 176 103
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125 98 70 75 114 179 156 151 138 146 89 99 101 108 122 59 65 111 130 81
77 114 120 92 108 116 124 129 187 168 95 76 104 126 108 96 124 118 99 92
115 107 95 70 116 78 45 70 133 168 170 194 150 116 71 79 119 110 109 61
76 62 65 65 88 64 72 99 66 75 93 93 108 116 79 88 103 89 112 131
134 137 118 157 132 132 144 113 126 112 109 98 75 98 63 90 82 78 103 110
72 88 44 52 99 68 83 71 81 68 51 47 68 90 87 94 70 89 98
PFR-B04A 42
76 117 133 201 312 273 197 224 217 135 139 152 153 160 114 87 115 277 143 236
332 291 172 229 258 205 270 507 378 214 255 328 301 345 229 313 254 248 216 184
129 151
PFR-B04B 42
81 127 131 190 316 263 200 252 203 138 154 155 172 148 99 70 150 318 157 190
337 317 208 220 243 215 261 486 408 208 239 325 299 341 232 314 254 260 208 181
124 158
PFR-B06A 52
150 77 99 132 142 166 173 133 99 104 179 100 71 109 121 229 162 82 116 156
145 190 170 179 165 132 94 55 77 66 141 193 178 147 157 99 116 151 151 97
80 106 95 87 95 205 132 131 69 104 89 106
PFR-B06B 62
106 110 95 205 253 146 165 178 264 233 212 186 88 101 98 101 179 193 190 159
82 94 140 164 179 189 142 103 109 185 107 75 133 128 250 181 86 115 142 153
195 174 163 152 124 104 57 88 64 145 186 172 140 153 120 123 161 154 91 77
114 108

APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

Tree-ring dating, or dendrochronology as it is known, is discussed in some detail in the Nottingham Tree-ring Dating Laboratory's Monograph, *An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Buildings* (Laxton and Litton 1988) and *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates* (English Heritage 1988). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The width of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure A1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths for oaks, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of oak timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring.

If the bark is still on the sample, as in Figure A1, then the date of the last ring will be the date of felling of the oak from which it was cut. There is much evidence that in medieval times oaks cut down for building purposes were used almost immediately, usually within the year or so (Rackham 1976). Hence if bark is present on several main timbers in a building, none of which appear reused or are later insertions, and if they all have the same date for their last ring, then we can be quite confident that this is the date of construction or soon after. If there is no bark on the sample, then we have to make an estimate of the felling date; how this is done is explained below.

The Practice of Tree-Ring Dating at the Nottingham Tree-Ring Dating Laboratory

1. **Inspecting the Building and Sampling the Timbers.** Together with a building historian the timbers in a building are inspected to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample *in situ* timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique

position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure A2 has about 120 rings; about 20 of which are sapwood rings — the lighter rings on the outside. Similarly the core has just over 100 rings with a few sapwood rings.

To ensure that we are getting the date of the building as a whole, or the whole of a phase of construction if there is more than one, about 8–10 samples per phase are usually taken. Sometimes we take many more, especially if the construction is complicated. One reason for taking so many samples is that, in general, some will fail to give a date. There may be many reasons why a particular sequence of ring widths from a sample of timber fails to give a date even though others from the same building do. For example, a particular tree may have grown in an odd ecological niche, so odd indeed that the widths of its rings were determined by factors other than the local climate! In such circumstances it will be impossible to date a timber from this tree using the master sequence whose widths, we can assume, were predominantly determined by the local climate at the time.

Sampling is done by coring into the timber with a hollow corer attached to an electric drill and usually from its outer rings inwards towards where the centre of the tree, the pith, is judged to be. An illustration of a core is shown in Figure A2; it is about 150mm long and 10mm diameter. Great care has to be taken to ensure that as few as possible of the outer rings are lost in coring. This can be difficult as these outer rings are often very soft (see below on sapwood). Each sample is given a code which identifies uniquely which timber it comes from, which building it is from and where the building is located. For example, CRO-A06 is the sixth core taken from the first building (A) sampled by the Laboratory in Cropwell Bishop. Where it came from in that building will be shown in the sampling records and drawings. No structural damage is done to any timbers by coring, nor does it weaken them.

During the initial inspection of the building and its timbers the dendrochronologist may come to the conclusion that, as far as can be judged, none of the timbers have sufficient rings in them for dating purposes and may advise against sampling to save further unwarranted expense.

All sampling by the Laboratory is undertaken according to current Health and Safety Standards. The Laboratory's dendrochronologists are insured.

Figure A1: A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976

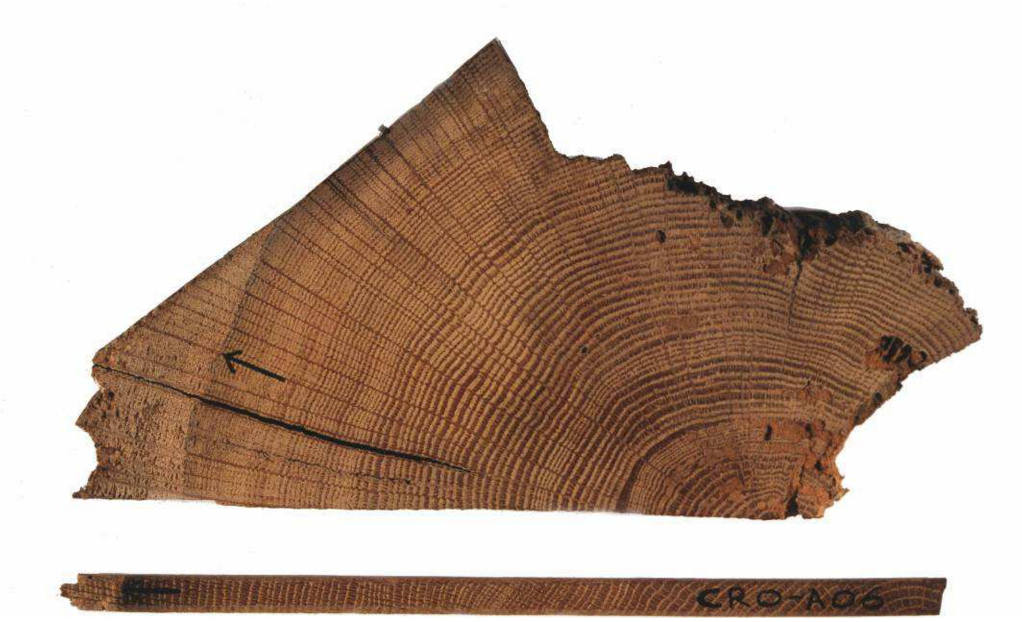


Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

Figure A3: Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measured twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis

Figure A4: Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical

2. Measuring Ring Widths. Each core is sanded down with a belt sander using medium-grit paper and then finished by hand with flourgrade-grit paper. The rings are then clearly visible and differentiated from each other with a result very much like that shown in Figure A2. The core is then mounted on a movable table below a microscope and the ring-widths measured individually from the innermost ring to the outermost. The widths are automatically recorded in a computer file as they are measured (see Fig A3).

3. Cross-Matching and Dating the Samples. Because of the factors besides the local climate which may determine the annual widths of a tree's rings, no two sequences of ring widths from different oaks growing at the same time are exactly alike (Fig A4). Indeed, the sequences may not be exactly alike even when the trees are growing near to each other. Consequently, in the Laboratory we do not attempt to match two sequences of ring widths by eye, or graphically, or by any other subjective method. Instead, it is done objectively (ie statistically) on a computer by a process called cross-matching. The output from the computer tells us the extent of correlation between two sample sequences of widths or, if we are dating, between a sample sequence of widths and the master, at each relative position of one to the other (offsets). The extent of the correlation at an offset is determined by the *t*-value (defined in almost any introductory book on statistics). That offset with the maximum *t*-value among the *t*-values at all the offsets will be the best candidate for dating one sequence relative to the other. If one of these is a master chronology, then this will date the other. Experiments carried out in the past with sequences from oaks of known date suggest that a *t*-value of at least 4.5, and preferably at least 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton and Litton 1988; Laxton *et al* 1988; Howard *et al* 1984–1995).

This is illustrated in Figure A5 with timbers from one of the roofs of Lincoln Cathedral. Here four sequences of ring widths, LIN-C04, 05, 08, and 45, have been cross-matched with each other. The ring widths themselves have been omitted in the bar diagram, as is usual, but the offsets at which they best cross-match each other are shown; eg the sequence of ring widths of C08 matches the sequence of ring widths of C45 best when it is at a position starting 20 rings after the first ring of C45, and similarly for the others. The actual *t*-values between the four at these offsets of best correlations are in the matrix. Thus at the offset of +20 rings, the *t*-value between C45 and C08 is 5.6 and is the maximum found between these two among all the positions of one sequence relative to the other.

It is standard practice in our Laboratory first to cross-match as many as possible of the ring-width sequences of the samples in a building and then to form an average from them. This average is called a site sequence of the building being dated and is illustrated in Figure A5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences of the four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. Thus in Figure A5 if the widths shown are 0.8mm for C45, 0.2mm for C08, 0.7mm for C05, and 0.3mm for C04, then the corresponding width of the site sequence is the average of these, 0.55mm. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

The straightforward method of cross-matching several sample sequences with each other one at a time is called the 'maximal *t*-value' method. The actual method of cross-matching a group of sequences of ring-widths used in the Laboratory involves grouping and averaging the ring-width sequences and is called the 'Litton-Zainodin Grouping Procedure'. It is a modification of the straightforward method and was successfully developed and tested in the Laboratory and has been published (Litton and Zainodin 1991; Laxton *et al* 1988).

4. **Estimating the Felling Date.** As mentioned above, if the bark is present on a sample, then the date of its last ring is the date of the felling of its tree (or the last full year before felling, if it was felled in the first three months of the following calendar year, before any new growth had started, but this is not too important a consideration in most cases). The actual bark may not be present on a timber in a building, though the dendrochronologist who is sampling can often see from its surface that only the bark is missing. In these cases the date of the last ring is still the date of felling.

Quite often some, though not all, of the original outer rings are missing on a timber. The outer rings on an oak, called sapwood rings, are usually lighter than the inner rings, the heartwood, and so are relatively easy to identify. For example, sapwood can be seen in the corner of the rafter and at the outer end of the core in Figure A2, both indicated by arrows. More importantly for dendrochronology, the sapwood is relatively soft and so liable to insect attack and wear and tear. The builder, therefore, may remove some of the sapwood for precisely these reasons. Nevertheless, if at least some of the sapwood rings are left on a sample, we will know that not too many rings have been lost since felling so that the date of the last ring on the sample is only a few years before the date of the original last ring on the tree, and so to the date of felling.

Various estimates have been made and used for the average number of sapwood rings in mature oak trees (English Heritage 1998). A fairly conservative range is between 15 and 50 and that this holds for 95% of mature oaks. This means, of course, that in a small number of cases there could be fewer than 15 and more than 50 sapwood rings. For example, the core CRO-A06 has only 9 sapwood rings and some have obviously been lost over time — either they were removed originally by the carpenter and/or they rotted away in the building and/or they were lost in the coring. It is not known exactly how many sapwood rings are missing, but using the above range the Laboratory would estimate between a minimum of 6 (=15–9) and a maximum of 41 (=50–9). If the last ring of CRO-A06 has been dated to 1500, say, then the estimated felling-date range for the tree from which it came originally would be between 1506 and 1541. The Laboratory uses this estimate for sapwood in areas of England where it has no prior information. It also uses it when dealing with samples with very many rings, about 120 to the last heartwood ring. But in other areas of England where the Laboratory has accumulated a number of samples with complete sapwood, that is, no sapwood lost since felling, other estimates in place of the conservative range of 15 to 50 are used. In the East Midlands (Laxton *et al* 2001) and the east to the south down to Kent (Pearson 1995) where it has sampled extensively in the past, the Laboratory uses the shorter estimate of 15 to 35 sapwood rings in 95% of mature oaks growing in these parts. Since the sample CRO-A06 comes from a house in Cropwell Bishop in the East Midlands, a better estimate of sapwood rings lost since felling is between a minimum of 6 (=15–9) and 26 (=35–9) and the felling would be estimated to have taken place between 1506 and 1526, a shorter period than before. Oak boards quite often come from the Baltic region and in these cases the 95% confidence limits for sapwood are 9 to 36 (Howard *et al* 1992, 56).

Even more precise estimates of the felling date and range can often be obtained using knowledge of a particular case and information gathered at the time of sampling. For example, at the time of sampling the dendrochronologist may have noted that the timber from which the core of Figure A2 was taken still had complete sapwood but that some of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 20mm, a reasonable estimate can be made of the number of sapwood rings lost, say 12 to 15 rings in this case. By adding on 12 to 15 years to the date of the last ring on the sample a good tight estimate for the range of the felling date can be obtained, which is often better than the 15 to 35 years later we would have estimated without this observation. In the example, the felling is now estimated to have taken place between AD 1512 and 1515, which is much more precise than without this extra information.

Even if all the sapwood rings are missing on a sample, but none of the heartwood rings are, then an estimate of the felling-date range is possible by adding on the full compliment of, say, 15 to 35 years to the date of the last heartwood ring (called the heartwood/ sapwood boundary or transition ring and denoted H/S). Fortunately it is often easy for a trained dendrochronologist to identify this boundary on a timber. If a timber does not have its heartwood/sapwood boundary, then only a *post quem* date for felling is possible.

5. Estimating the Date of Construction. There is a considerable body of evidence collected by dendrochronologists over the years that oak timbers used in buildings were not seasoned in medieval or early modern times (English Heritage 1998; Miles 1997, 50–5). Hence, provided that all the samples in a building have estimated felling-date ranges broadly in agreement with each other, so that they appear to have been felled as a group, then this should give an accurate estimate of the period when the structure was built, or soon after (Laxton *et al* 2001, Fig 8; 34–5, where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storage before use, or if there is evidence the oak came from abroad (eg Baltic boards), then some allowance has to be made for this.

6. Master Chronological Sequences. Ultimately, to date a sequence of ring widths, or a site sequence, we need a master sequence of dated ring widths with which to cross-match it, a Master Chronology. To construct such a sequence we have to start with a sequence of widths whose dates are known and this means beginning with a sequence from an oak tree whose date of felling is known. In Figure A6 such a sequence is SHE-T, which came from a tree in Sherwood Forest which was blown down in a recent gale. After this other sequences which cross-match with it are added and gradually the sequence is 'pushed back in time' as far as the age of samples will allow. This process is illustrated in Figure A6. We have a master chronological sequence of widths for Nottinghamshire and East Midlands oak for each year from AD 882 to 1981. It is described in great detail in Laxton and Litton (1988), but the components it contains are shown here in the form of a bar diagram. As can be seen, it is well replicated in that for each year in this period there are several sample sequences having widths for that year. The master is the average of these. This master can now be used to date oak from this area and from the surrounding areas where the climate is very similar to that in the East Midlands. The Laboratory has also constructed a master for Kent (Laxton and Litton 1989). The method the Laboratory uses to construct a master sequence, such as the East Midlands and Kent, is completely objective and uses the Litton-Zainodin grouping procedure (Laxton *et al* 1988). Other laboratories and individuals have constructed masters for other areas and have made them available. As well as these masters, local (dated) site chronologies can be used to date other buildings from nearby. The Laboratory has hundreds of these site sequences from many parts of England and Wales covering many short periods.

7. Ring-Width Indices. Tree-ring dating can be done by cross-matching the ring widths themselves, as described above. However, it is advantageous to modify the widths first. Because different trees grow at different rates and because a young oak grows in a different way from an older oak, irrespective of the climate, the widths are first standardized before any matching between them is attempted. These standard widths are known as ring-width indices and were first used in dendrochronology by Baillie and Pilcher (1973). The exact form they take is explained in this paper and in the appendix of Laxton and Litton (1988) and is illustrated in the graphs in Figure A7. Here ring-widths are plotted vertically, one for each year of growth. In the upper sequence of (a), the generally large early growth after 1810 is very apparent as is the smaller later growth from about 1900 onwards when the tree is maturing. A similar phenomenon can be observed in the lower sequence of (a) starting in 1835. In both the widths are also changing rapidly from year to year. The peaks are the wide rings and the troughs are the narrow rings corresponding to good and poor growing seasons, respectively. The two corresponding sequence of Baillie-Pilcher indices are plotted in (b) where the differences in the immature and mature growths have been removed and only the rapidly changing peaks and troughs remain, that are associated with the common climatic signal. This makes cross-matching easier.

t-value/offset Matrix

	C45	C08	C05	C04
C45		+20	+37	+47
C08	5.6		+17	+27
C05	5.2	10.4		+10
C04	5.9	3.7	5.1	

Bar Diagram

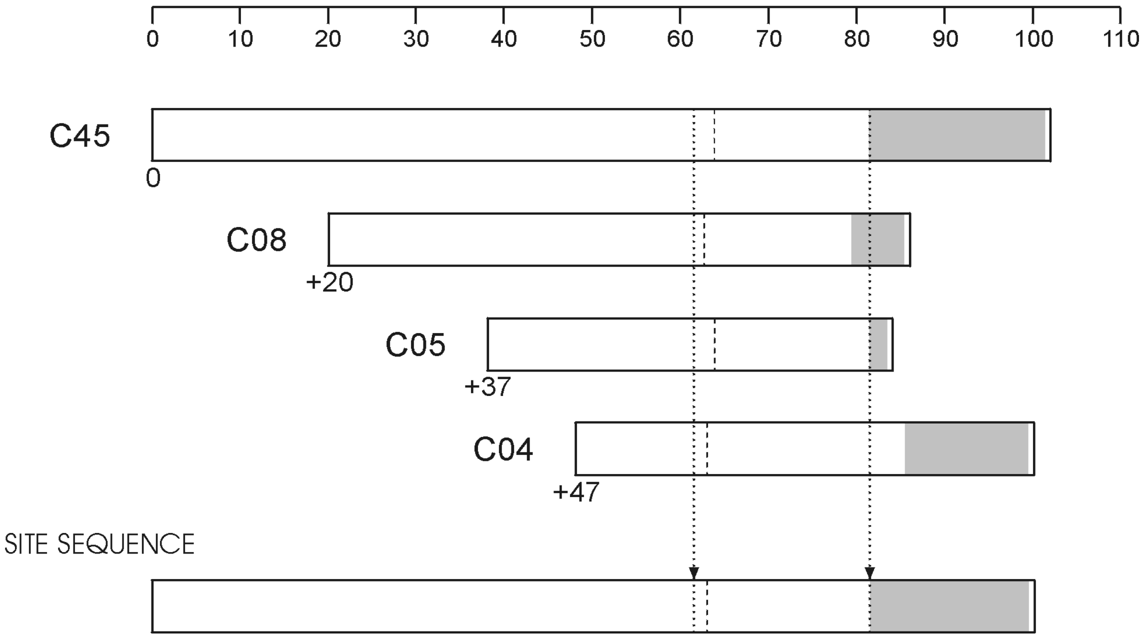


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

The bar diagram represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set at relative positions (offsets) to each other at which they have maximum correlation as measured by the *t*-values. The *t*-value/offset matrix contains the maximum *t*-values below the diagonal and the offsets above it. Thus, the maximum *t*-value between C08 and C45 occurs at the offset of +20 rings and the *t*-value is then 5.6. The site sequence is composed of the average of the corresponding widths, as illustrated with one width.

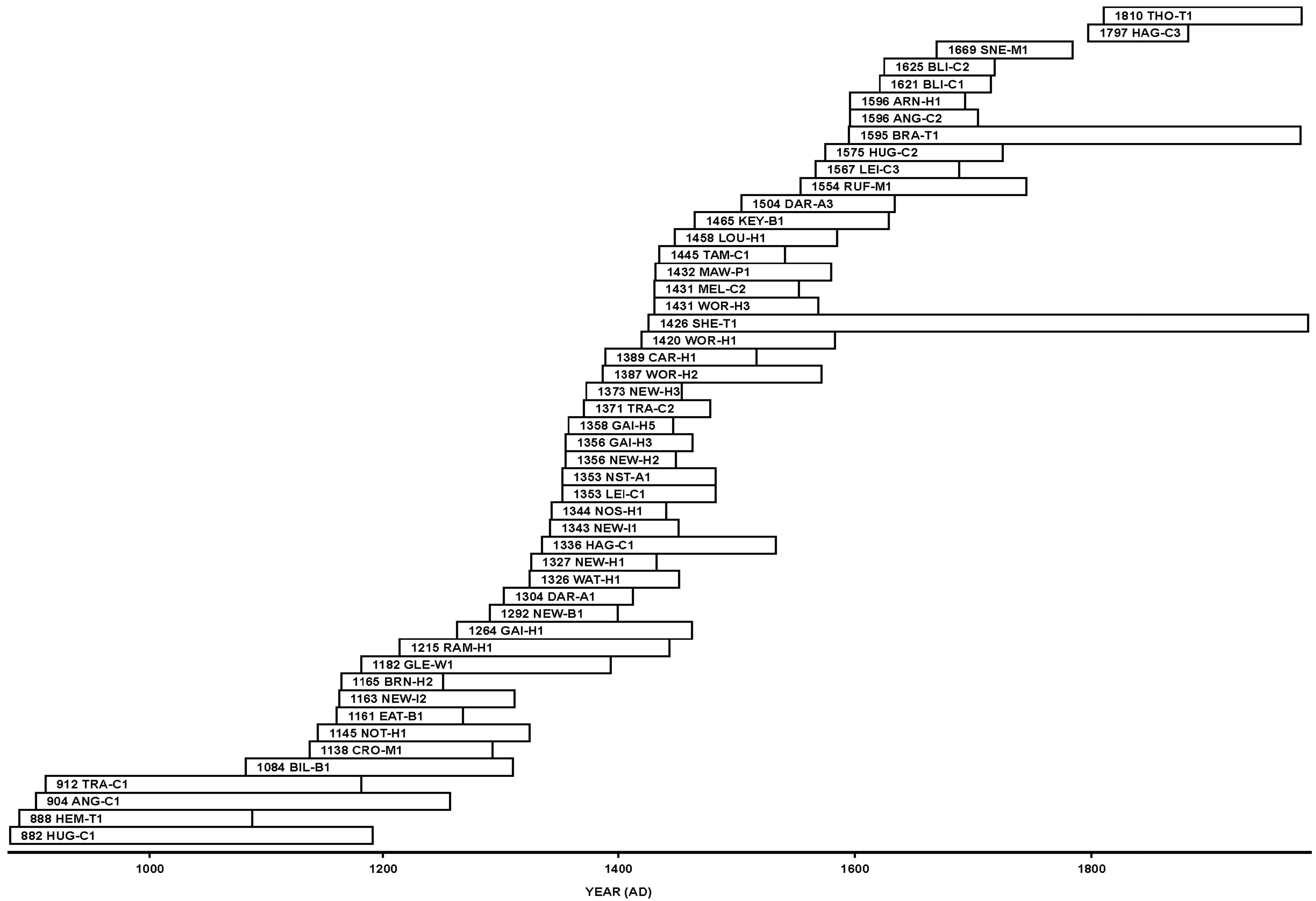
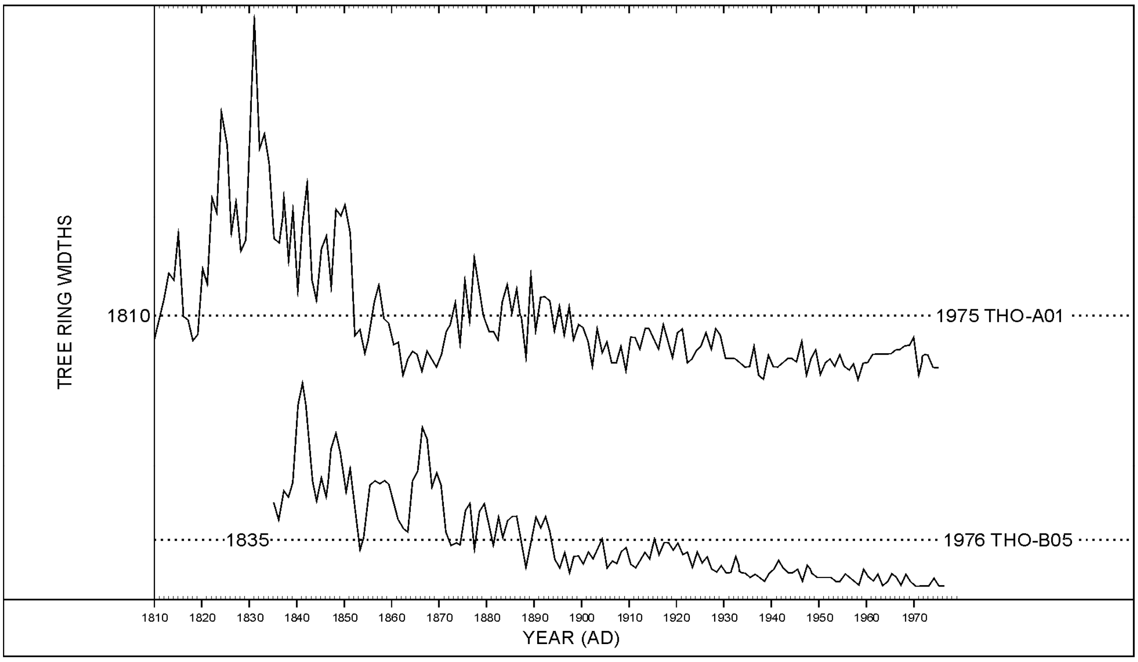


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

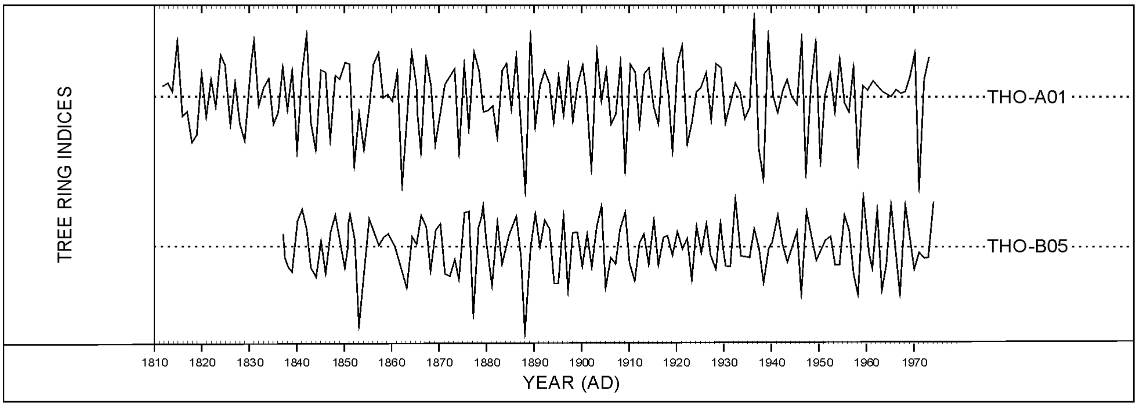


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree are wider than the later ones of the older tree in both sequences.

Figure A7 (b): The Baillie-Pilcher indices of the above widths

The growth trends have been removed completely.

References

Baillie, M G L, and Pilcher, J R, 1973 A simple cross-dating program for tree-ring research, *Tree-Ring Bull*, 33, 7–14

English Heritage, 1998 *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates*, London

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1984–95 Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect*, 15–26

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1992 List 44 no 17 - Nottingham University Tree-Ring Dating Laboratory: tree-ring dates for buildings in the East Midlands, *Vernacular Architect*, 23, 51–6.

Laxton, R R, Litton, C D, and Zainodin, H J, 1988 An objective method for forming a master ring-width sequence, *P A C T*, 22, 25–35

Laxton, R R, and Litton, C D, 1988 *An East Midlands Master Chronology and its use for dating vernacular buildings,* University of Nottingham, Department of Archaeology Publication, Monograph Series III

Laxton, R R, and Litton, C D, 1989 Construction of a Kent master dendrochronological sequence for oak, AD 1158 to 1540, *Medieval Archaeol*, 33, 90–8

Laxton, R R, Litton, C D, and Howard, R E, 2001 *Timber: Dendrochronology of Roof Timbers at Lincoln Cathedral*, Engl Heritage Res Trans, 7

Litton, C D, and Zainodin, H J, 1991 Statistical models of dendrochronology, *J Archaeol Sci*, 18, 29–40

Miles, D W H, 1997 The interpretation, presentation and use of tree-ring dates, *Vernacular Architect*, 28, 40–56

Pearson, S, 1995 *The Medieval Houses of Kent, an Historical Analysis,* London

Rackham, O, 1976 *Trees and Woodland in the British Landscape*, London



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